

**Title: HOT WHEELS**

An investigation of acceleration and quadratic equations through discovery and exploration of toy Hot Wheels cars and motion.

**Link to Outcomes:**

- **Communication** Students will discuss mathematical and physical concepts with other students.
- **Reasoning** Students will collect data, make conjectures, and test them. Students will base conclusions on observations.
- **Connections** Students will observe connections between physical experiment and quadratic equation concepts.
- **Measurement** Students will use Calculator Based Laboratory (CBL) and motion probe to measure acceleration.
- **Algebra** Students will create equations based on quadratic regression models.
- **Trigonometry** As an extension, students will calculate the angle of inclination using the sine function and will approximate the sine curve.
- **Technology** Students will use the CBL with Vernier motion detector and the TI-82 graphics calculator (TI-82).
- **Statistics** Students will select relevant and discard extraneous data.
- **Cooperation** Students will work in heterogenous groups of two or three with specific roles assigned to each.
- **Processes of Science** Students will hypothesize, conduct experiments, and test hypotheses based on observations.

**Brief Overview:**

Galileo in the 17th century approximated the force of gravity using a series of inclined planes without sophisticated equipment. The students will duplicate Galileo's experiment using the CBL and the TI-82. The use of these tools have allowed us to simplify this ancient experiment as well as make it more accurate. The students investigate the principle of acceleration as a quadratic function. The students collect data to determine that the force of gravity is a function of the angle of inclination.

**Grade/Level:**

Grades 10-12: Algebra II/Physics

**Duration:**

This lesson takes two fifty-minute classes or one 100-minute class period.

**Prerequisite Knowledge:**

Students need to be familiar with the following:

- linear regression
- quadratic equations
- TI-82

**Objectives:**

Students will:

- collect data using the TI-82, CBL, and motion detector.
- select relevant data.
- perform quadratic regression to determine the appropriate quadratic equation.
- extrapolate from the equation the effect of gravity for the given slope.

**Materials/Resources/Printed Materials:**

- TI-82 with HOT WHEELS, ALL SELECT, and SORTLIST programs (See Appendix A)
- CBL
- CBL Set Up (Appendix B)
- Vernier Ultrasonic Motion Detector
- Matchbox cars
- Inclined plane (six-foot board or table)
- Masking tape
- Teacher Notes (Reference 1)
- Student Notes (Reference 2)
- Student Worksheets (Reference 3)

This experiment has been adapted from the book *Exploring Physics and Math with CBL System* by Chris Brueningsen and Wesley Krawiec. The programs ALL SELECT and HOT WHEELS have been adapted from the programs SELECT and BALLDROP respectively from the same source.

**Development/Procedures:**

Prior to CBL lab experience, introduce the concept of acceleration as a function of angle of inclination. Divide the students into groups and ask them to set up experiment. Perform the seven trials, and determine the quadratic regression equation for each trial. Record the data to complete the table. Plot the acceleration as a function of the angle of inclination.

**Evaluation:**

Check the completion and accuracy of the data table.  
Evaluate the sketch of the acceleration curve.

**Extensions:**

Demonstrate to students that small sampling size of data may lead to erroneous conclusions.  
Explanation of Challenger disaster, faulty “O” rings, as an example of incorrect modeling.

**Authors:**

Vicky Eastham  
Rappahannock County H.S.  
Rappahannock County

Phillip Sanderson  
Mathews High School  
Mathews County

## TEACHER NOTES

### PreLab:

TI-82: The following programs may be found in Appendix A and must be loaded or typed into the calculator prior to the lab: HOT WHEELS, ALL SELECT, and SORTLIST.

Introduction: The physics or physical science teacher makes an excellent resource to review the principles of velocity and acceleration, with a special emphasis on objects and free fall motion and the equation which models it.

### Set-up of Lab:

1. Mount the motion probe at one end of the board or table.
2. Measure 18 inches from the front of the probe, and mark using tape.

*If the ramp the students use is not six feet, as is suggested, you will need to recalculate the angle of inclination. If students are familiar with the inverse sine function, they may calculate the angle of inclination of the ramp as an extension activity.*

3. Incline the board to the first height indicated on the Student Worksheet (Reference 3).

*The motion detector probe must be put into the sonic port and will only fit in one way.*

*If this is used as a teacher demonstration, connect the TI-82 Viewscreen cable to the top of the calculator (Be sure proper side is facing upward when attaching the cable.).*

4. Attach the motion probe, CBL, and TI-82 together. (See Instructions in Appendix B.)

### Experiment:

5. Having turned on both units, press [PRGM] to access the program execute menu. Arrow down to find the HOT WHEELS program, and press enter to run.
6. While the HOT WHEELS program is running (there will be a faint clicking sound coming from the motion detector), line up the car so that the rear bumper is on the 18-inch line.
7. Press [TRIGGER] on the CBL unit while at the same time releasing the car.

*The motion detector will operate properly only if the object it is tracking is a minimum of 18 inches from the sensor. In addition the probe has a maximum “line of sight” of 20 degrees to the left and right from perpendicular to the face of the motion detector.*

### Selecting Relevant Data:

8. If your graph on the calculator does **not** contain data plots that are extraneous, skip this section and move on to step 13, Determining the Equation.
9. Press [PRGM] to access the program execute menu. Arrow down to ALL SELECT, and press [ENTER] to run.
10. ALL SELECT will prompt for the location of the data that will be the X-list and the Y-list. Choose  $L_1$  for the X-list, and choose  $L_2$  for the Y-list.
11. Use the arrow keys to move the trace cursor (the “spider”) to the left-most region of good points, and press [ENTER]. Move the trace cursor to the right-most region of good data, and press [ENTER] again.
12. Press [ENTER] to see the plot as prompted.

### Determining the Equation:

13. Press [2nd][QUIT] to reach the home screen.
14. Press [STAT] to enter the statistics menu.  
Arrow to the right to pull down the CALC menu.  
Choose QuadReg. This command will now be copied to your home screen.
15. If ALL SELECT ran during the previous section, follow the QuadReg command with “ $L_3, L_4$ ” to indicate first the location of the X-list and then the location of the Y-list.

If ALL SELECT did not run, follow the QuadReg command with “ $L_1, L_2$ .”

The format of the quadratic equation and the values of the constants that determine the specific equation will be copied to the home screen.

*Students may need help, initially, locating where to find the list names. They are located above the numerical keys 1, 2,...6*

16. Enter into the chart on the first page of the Student Worksheet (Reference 3) the equation (take the decimal places to 3 significant figures), the value of the quadratic coefficient, and the calculated acceleration.
17. Perform steps 5-16 for the remaining heights given on the chart.

### Determining Acceleration:

18. Press [STAT], and arrow down to ClrList. Press [ENTER] to choose, and the command will be copied to the home screen.
19. Follow the ClrList command with “ $L_1, L_2$ .”
20. Press [STAT], and choose the Edit command by pressing [ENTER].
21. In  $L_1$ , enter the Angle of Inclination for each of the given heights from the chart and enter the Acceleration into  $L_2$  for each of the heights as well.
22. Press [ZOOM], and arrow down to ZoomStat to see a plot of the data.

23. Use the same method as previously described under Determining the Equation to perform quadratic regression on the data currently entered. Be sure that you are regressing  $L_1$  against  $L_2$ .

*The plot of data students see when comparing angle of inclination to acceleration may initially look like a quadratic equation, which is why the lab suggests to regress the equation accordingly. Note that it is **not** quadratic. The equation is actually a sine curve ( $a = g\sin\theta$ ). Other regression equations may be tried to match the data, but this is an important exercise for students to see that what may look like a good fit on a close level fails when the larger view is considered. This can be in turn related to what happened to the scientists preparing the “O” rings for the Challenger shuttle, whereby their data was not taken to a low enough temperature.*

### **Graphing the Quadratic Regression Equation to Match the StatPlot:**

24. Press [Y=] to access the equation list. Clear any equations currently entered.  
Press [VARS].  
Arrow down to Statistics, and choose it.  
Arrow to the right to pull down the menu under EQ.  
Arrow down to RegEq, and choose it.  
This will copy the regression equation into the “Y =” list.
25. Press [GRAPH] to see the regression equation as it is drawn over the plotted data points.
26. Sketch this graph on the worksheet--include both the line and the data points. Write the regression equation for this below the graph.
27. Answer all questions.

## Student Notes

### Set-up of Lab:

1. Mount the motion probe at one end of the board or table.
2. Measure 18 inches from the front of the probe, and mark using tape.
3. Incline the board to the first height indicated on the Student Worksheet (Reference 3).
4. Attach the motion probe, CBL, and TI-82 together. (See Instructions in Appendix B)

### Experiment:

5. Having turned on both units, press [PRGM] to access the program execute menu. Arrow down to find the HOT WHEELS program, and press enter to run.
6. While the HOT WHEELS program is running (there will be a faint clicking sound coming from the motion detector), line up the car so that the rear bumper is on the 18-inch line.
7. Press [TRIGGER] on the CBL unit while at the same time releasing the car.

### Selecting Relevant Data:

8. If your graph on the calculator does **not** contain data plots that are extraneous, skip this section and move on to step 13, Determining the Equation.
9. Press [PRGM] to access the program execute menu. Arrow down to ALL SELECT, and press [ENTER] to run.
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11. Use the arrow keys to move the trace cursor (the “spider”) to the left-most region of good points, and press [ENTER]. Move the trace cursor to the right-most region of good data, and press [ENTER] again.
12. Press [ENTER] to see the plot as prompted.

### Determining the Equation:

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17. Perform steps 5-16 for the remaining heights given on the chart.

### **Determining Acceleration:**

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19. Follow the ClrList command with " $L_1, L_2$ ."
20. Press [STAT], and choose the Edit command by pressing [ENTER].
21. In  $L_1$ , enter the Angle of Inclination for each of the given heights from the chart and enter the Acceleration into  $L_2$  for each of the heights as well.
22. Press [ZOOM], and arrow down to ZoomStat to see a plot of the data.
23. Use the same method as previously described under Determining the Equation to perform quadratic regression on the data currently entered. Be sure that you are regressing  $L_1$  against  $L_2$ .

### **Graphing the Quadratic Regression Equation to Match the StatPlot:**

24. Press [Y=] to access the equation list. Clear any equations currently entered. Press [VARS].  
Arrow down to Statistics, and choose it.  
Arrow to the right to pull down the menu under EQ.  
Arrow down to RegEq, and choose it.  
This will copy the regression equation into the " $Y =$ " list.
25. Press [GRAPH] to see the regression equation as it is drawn over the plotted data points.
26. Sketch this graph on the worksheet--include both the line and the data points. Write the regression equation for this below the graph.
27. Answer all questions.



**Student Worksheet**

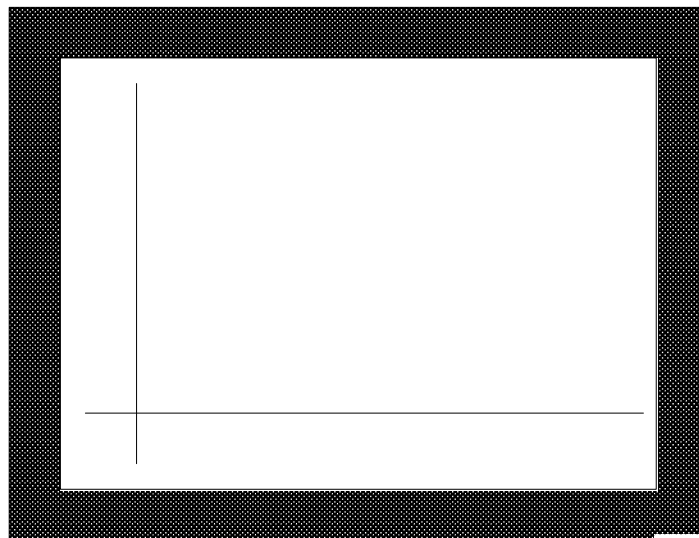
Name: \_\_\_\_\_

Date: \_\_\_\_\_

Pd.: \_\_\_\_\_

Table Height	Angle of Inclination	Regression Equation	Quadratic Coefficient	Acceleration ( col. 2 x col. 4)
2"	1.59			
4"	3.18			
5"	3.98			
6"	4.78			
8"	6.38			
10"	7.98			
12"	9.59			

Sketch the graph created on TI-82 calculator below. (Col. 2 v. Col. 5.)



Regression equation: Acceleration v. Angle \_\_\_\_\_

Answer the following questions:

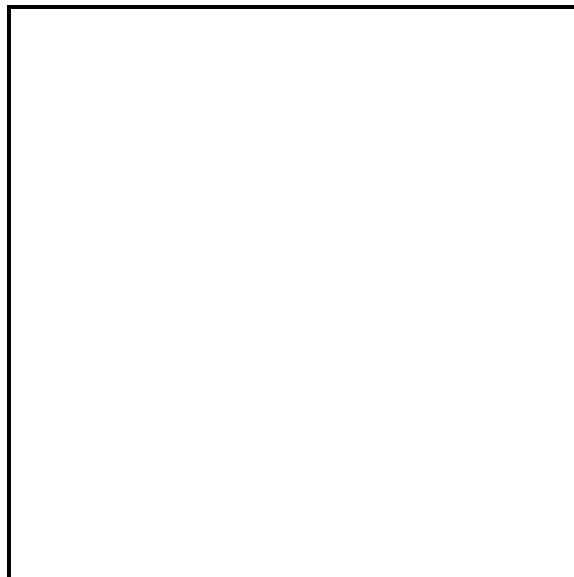
1. Name three sources of error introduced during the lab:
  - a.
  - b.
  - c.
2. How would the data be different if the vehicle were a Tonka truck?

How about if it were a Mac truck? (Please make an appropriate change in the ramp as well.)

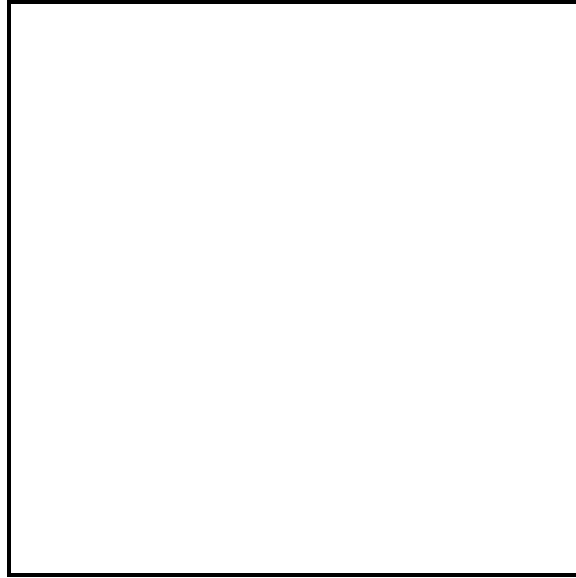
3. How would the data change if you used a twelve-foot ramp?

How about a 100-yard ramp?

4. Draw the graph below of a Hot Wheels car with a parachute attached to the back of it for a six-foot ramp at a 5 degree inclination:



5. Draw the graph below of an aerodynamically sound Hot Wheels car for the same ramp in No. 4.



6. Make a prediction (use trace to follow the equations graph on the TI-82, if you like). What do you think the acceleration would equal if the measure of the angle of inclination was 90 degrees?

## Appendix A

### CBL Programs Used for HOT WHEELS Lab

#### HOT WHEELS

```
ClrList L1, L2, L3, L4, L5, L6
PlotsOff
FnOff
AxesOn
{1,0}→L1
Send(L1)
{1,11,3}→L1
Send(L1)
Disp “ ”
Disp “PRESS TRIGGER”
Disp “AND RELEASE”
Disp “OBJECT AT”
Disp “SAME TIME”
Disp “WHEN READY”
{3,.03,90,1,0,0,0,0,1}→L1
Send(L1)
ClrList L1, L2
Get(L2)
Get(L1)
Plot1(Scatter, L1, L2, .)
1→Xscl
1→Yscl
ZoomStat
Text(0,12,“DIST”)
Text(57,50,“TIME”)
Stop
```

## SORTLIST

```
ClrHome
Menu("WHERE IS X-LIST?", "L1", 1, "L2", 2, "L3", 3, "L4", 4, "L5", 5, "L6", 6)
Lbl 1:1→Q:Goto 0
Lbl 2:2→Q:Goto 0
Lbl 3:3→Q:Goto 0
Lbl 4:4→Q:Goto 0
Lbl 5:5→Q:Goto 0
Lbl 6:6→Q:Goto 0
Lbl 0
ClrHome
Menu("WHERE IS Y-LIST?", "L1", A, "L2", B, "L3", C, "L4", D, "L5", E, "L6", F)
Lbl A:1→R:Goto G
Lbl B:2→R:Goto G
Lbl C:3→R:Goto G
Lbl D:4→R:Goto G
Lbl E:5→R:Goto G
Lbl F:6→R:Goto G
Lbl G
If R=1 and Q≠
3
Then:L1→L3:Goto H:End
If R=1 and Q=3
Then:L1→L2:Goto H:End
Lbl H
If Q=2
Then:L2→L1:Goto J:End
If Q=3
Then:L3→L1:Goto J:End
If Q=4
Then:L4→L1:Goto J:End
If Q=5
Then:L5→L1:Goto J:End
If Q=6
Then:L6→L1:Goto J:End
Lbl J
If R=1 and Q≠3
Then:L3→L2:Goto K:End
If R=3
Then:L3→L2:Goto K:End
If R=4
Then:L4→L2:Goto K:End
If R=5
Then:L5→L2:Goto K:End
If R=6
```

```
Then:  $L_6 \rightarrow L_2$ :Goto K:End  
Lbl K  
ClrList  $L_3, L_4, L_5, L_6$   
Return  
Stop
```

## ALL SELECT

```
ClrHome
Disp "YOU WILL NEED"
Disp "TO KNOW THE LIST"
Disp "UNDER WHICH THE"
Disp "X-LIST AND"
Disp "Y-LIST ARE"
Disp "STORED TO"
Disp "CONTINUE"
Pause
prgmSORTLIST
ClrHome
ClrDraw
FnOff
PlotsOff
AxesOn
Plot1(xyLine,L1,L2,. . .)
ZoomStat
Text(2,2,"LOWER BOUND?")
Trace
X→A
Vertical A
Text(2,2,"UPPER BOUND? ")
Trace
X→B
Vertical B
dim L1→N
1→C
Text(2,2,"ANALYZING... ")
For(I,1,N,1)
If L1(I)≥A and L1(I)≤B
Then
L1(I)→L3(C)
L2(I)→L4(C)
C+1→C
End
End
ClrHome
Disp "X-LIST: L3"
Disp "Y-LIST: L4"
Disp ""
Disp "HIT ENTER TO SEE"
Disp "SELECTED PLOT."
Pause
Plot1(xyLine,L3,L4,...)
ZoomStat
Stop
```

## **Appendix B**

### **CBL Set Up**

1. Use the TI cable to cable link to join the CBL to the TI-82 calculator. The port in both units is found on the bottom. Make sure the link is pressed in far enough.
2. Connect the Vernier Ultrasonic Motion Detector to the Sonic port on the left-hand side of the CBL unit.
3. Turn on the calculator and the CBL. The CBL system is now ready to receive data from the motion detector and commands from the calculator.